

# Lesson 10: Culvert and Ditch Design (HM Chpt 3 & 4)



# Objectives



- Understand the different types of culverts
- Know the culvert design process for conveyance
- Complete a roadway culvert design using nomographs and determine headwater to diameter ratio ( $HW/d$ )
- Discuss the roadway ditch design and review the design criteria

# Culvert Design

A culvert is a closed conduit under a roadway or embankment used to maintain flow from a natural channel or drainage ditch. A culvert should convey flow without causing damaging backwater, excessive flow constriction, or excessive outlet velocities.

There are culverts for:

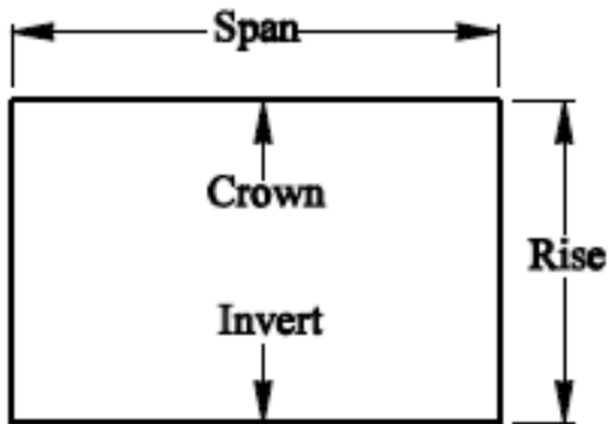
conveyance

fish passage (HM Chapter 3-3.1 and HM Chapter 7)

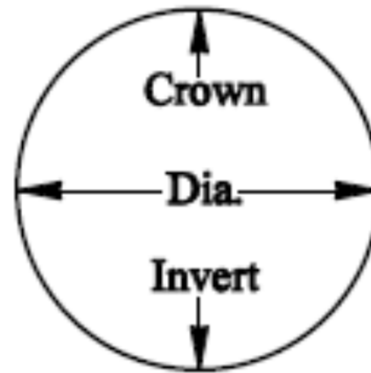
Temporary conditions (HM Chapter 3-3.1.1)

We will focus on a **conveyance culvert** in this lesson

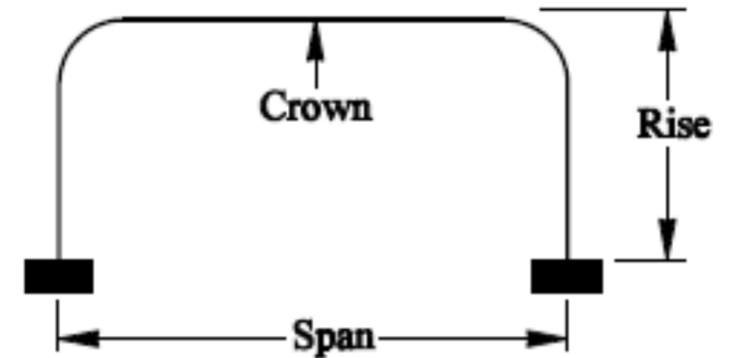
# Culvert Design



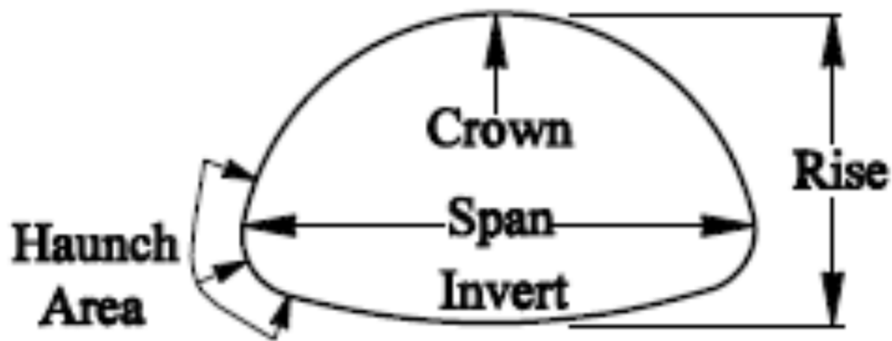
**Box Culvert**



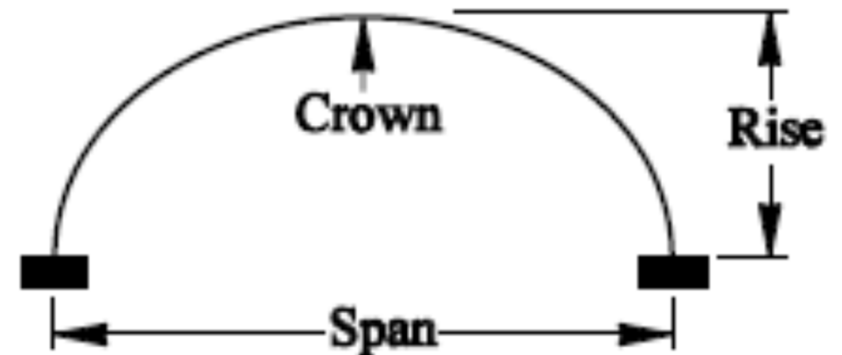
**Circular Culvert**



**3-Sided Box**



**Pipe Arch**



**Bottomless Arch**

# Culvert Design

Information and Field Data	Type A&B New Sites	Type B Extending or Replacing
1. Topographic survey	R	O
2. Ground cover description	R	O
3. Stream descriptions & investigation	R	O
4. Ground soil investigation	R	O
5. Streambed profile & alignment	R	O
6. Streambed cross section	R	O
7. Proposed roadway profile & alignment	R	O
8. Proposed roadway cross section	R	O
9 <sup>1</sup> . Corrosion Zone, pH, resistivity	<u>R<sup>1</sup></u>	<u>O<sup>1</sup></u>
10. Historical information	R	R
11. Fish passage	R	O
12. Unique features	R	O

1. Only required if replacing with dissimilar material.

R=REQUIRED, O=OPTION UNLESS NEW CULVERT

Field Data Requirements for Type A or B Hydraulic Reports

Figure 3-2.3

# Culvert Design Cheat Sheet

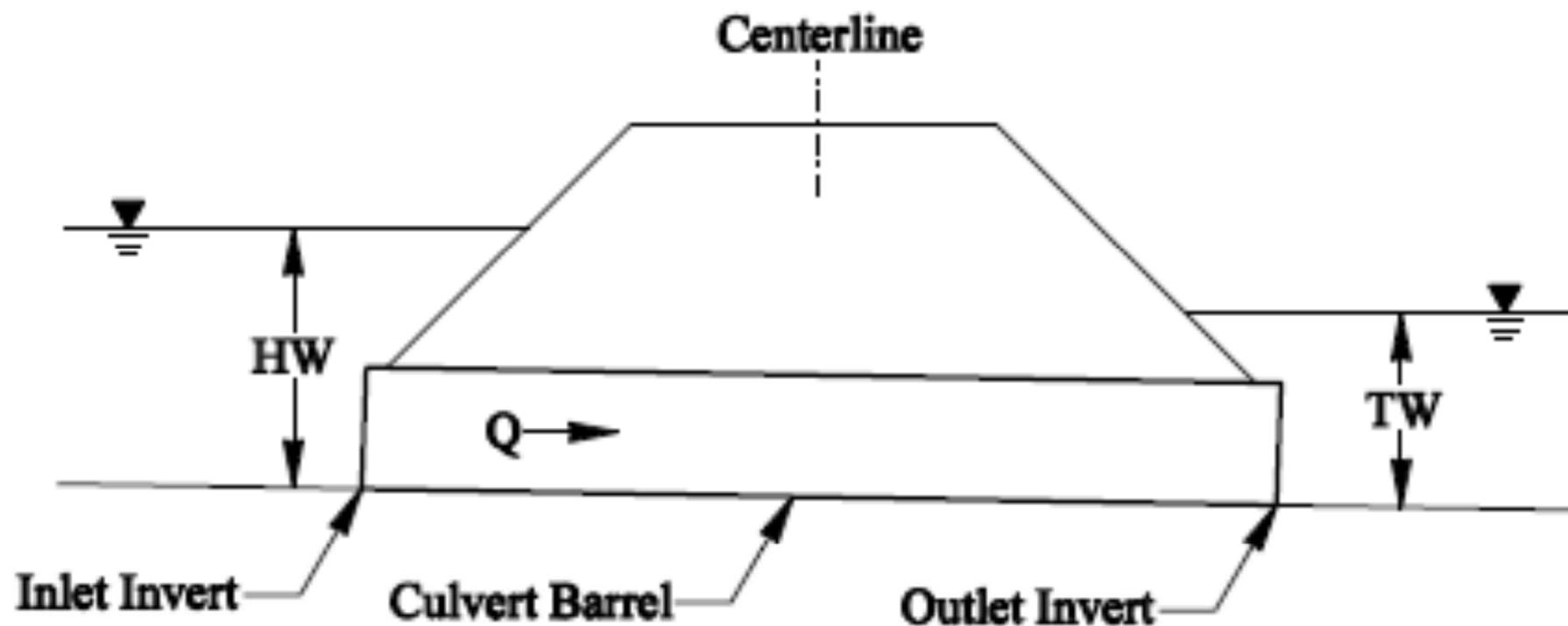
1. Minimum diameter = 18 inches; culverts under roadway approaches have a minimum diameter of 12 inches
2. No minimum velocity
3. No minimum pipe slope; 10% max for concrete, 20% max for corrugated metal and thermoplastic pipe
4. The headwater and tailwater conditions determine which equations (nomographs) are used for design
5. Culverts over 20 feet wide are designed as a bridge (see HM 3-3.1.2) and need a backwater and scour analysis
6. Generally design for the 25-year event and check the 100-year for overtopping of the highway



# Culvert Design Cheat Sheet

1. Interstate or major highway - Culvert must pass the 100-year flow with no overtopping of highway
2. Minor state highway - overtopping of highway may be allowed if it's more cost effective than installing more culverts to pass the 100-year flow
3. Bottomless culverts with footings should be designed to pass the 100-year flow with the headwater less than the top of the culvert. The 25-year should allow 1 foot of freeboard for debris flow.
4. Headwater to culvert diameter (HW/D) should be less than or equal to 1.25 though it can be up to 3 to 5 if approved by the Region Hydraulics Engineer or HQ Hydraulics Section under certain conditions.

# General Culvert Design Method



Headwater and Tailwater Diagram

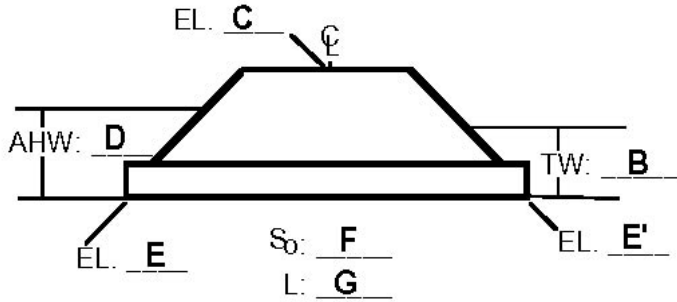
Figure 3-3.2.1



# General Culvert Design Method

1. Calculate the culvert design flows (Section 3-3.1)
2. Determine the allowable headwater elevation (Section 3-3.2)
3. Determine the tailwater elevation at the design flow (Section 3-3.3)
4. Determine the type of control that exists at the design flow(s), either inlet control or outlet control (Section 3-3.4)
5. Calculate outlet velocities (Section 3-3.5)
6. Provide outlet protection if high velocities

# General Culvert Design Method

Project: _____ Example _____			Designer: _____																																																																																																																																																																																
SR: _____			Date: _____																																																																																																																																																																																
Hydrologic and Channel Information  Q <sub>1</sub> : <u>A</u> TW <sub>1</sub> : <u>B</u> Q <sub>2</sub> : <u>A'</u> TW <sub>2</sub> : <u>B'</u> Q <sub>3</sub> : <u>A''</u> TW <sub>3</sub> : <u>B''</u>				Sketch  Station: _____  																																																																																																																																																																															
<table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <tr> <th colspan="3"></th> <th colspan="9">Headwater Computations</th> <th colspan="3"></th> </tr> <tr> <th colspan="3"></th> <th colspan="2">Inlet Control</th> <th colspan="7">Outlet Control</th> <th colspan="3"></th> </tr> <tr> <th>Column 1</th> <th>2</th> <th>3</th> <th>4</th> <th>5</th> <th>6</th> <th>7</th> <th>8</th> <th>9</th> <th>10</th> <th>11</th> <th>12</th> <th>13</th> <th>14</th> <th>15</th> </tr> <tr> <th>Culvert Type</th> <th>Q</th> <th>Size</th> <th><math>\frac{HW}{D}</math></th> <th>HW</th> <th><math>k_e</math></th> <th><math>d_c</math></th> <th><math>\frac{d_c + D}{2}</math></th> <th><math>h_0</math></th> <th>H</th> <th><math>LS_o</math></th> <th>HW</th> <th>Cont. HW</th> <th>Outlet Vel.</th> <th>Comments</th> </tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> </table>																		Headwater Computations															Inlet Control		Outlet Control										Column 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Culvert Type	Q	Size	$\frac{HW}{D}$	HW	$k_e$	$d_c$	$\frac{d_c + D}{2}$	$h_0$	H	$LS_o$	HW	Cont. HW	Outlet Vel.	Comments																																																																																																									
			Headwater Computations																																																																																																																																																																																
			Inlet Control		Outlet Control																																																																																																																																																																														
Column 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15																																																																																																																																																																					
Culvert Type	Q	Size	$\frac{HW}{D}$	HW	$k_e$	$d_c$	$\frac{d_c + D}{2}$	$h_0$	H	$LS_o$	HW	Cont. HW	Outlet Vel.	Comments																																																																																																																																																																					
Summary and Recommendations:																																																																																																																																																																																			

# Calculating Headwater

- It is an iterative process depending on if the culvert is flowing with inlet or outlet control (different equations for each condition)
- The headwater elevation will let you know how much ponding is on the upstream side of the culvert and if water might overtop or flow over the highway
- The headwater elevation will also give you an idea if any upstream flooding might occur so you can compare against potential property damage

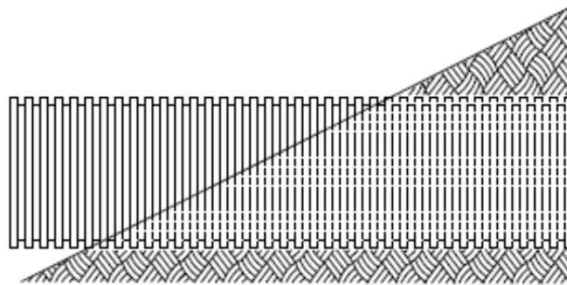
# Calculating Headwater

- Assuming the culvert is flowing with inlet control
  - act as an orifice if the inlet is submerged
  - act as a weir if inlet is unsubmerged
- Inlet and outlet control nomographs
  - HM Figures 3-3.4.2A to 3-3.4.2E are nomographs
  - Different pipe types (round, corrugated metal, pipe-arch, structural plate, and box culvert)
  - Use a square or straight edge to draw lines on the nomograph to figure out things

# Culvert Design

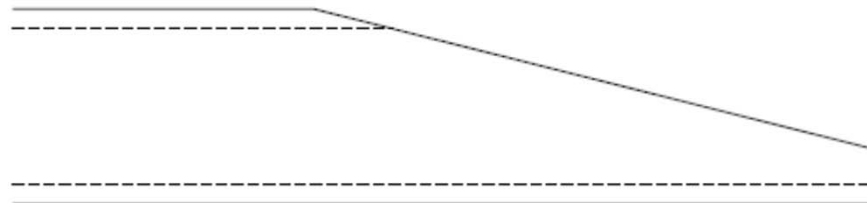
You can improve culvert efficiency by adding culvert end treatments (HM 3-4)

Some end treatments make the culvert safer such as beveled end sections



Projecting End

Figure 3-4.1

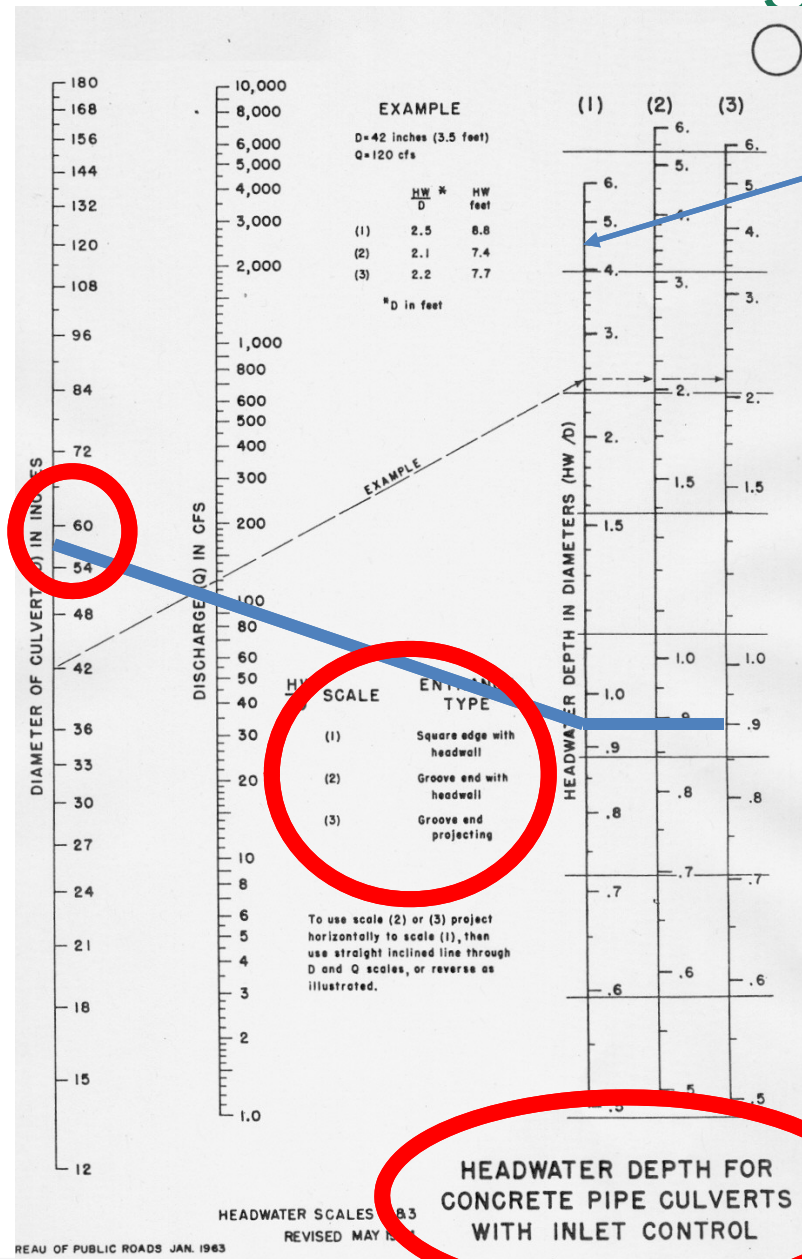


Beveled End Section

Figure 3-4.2

# Inlet Control Nomographs

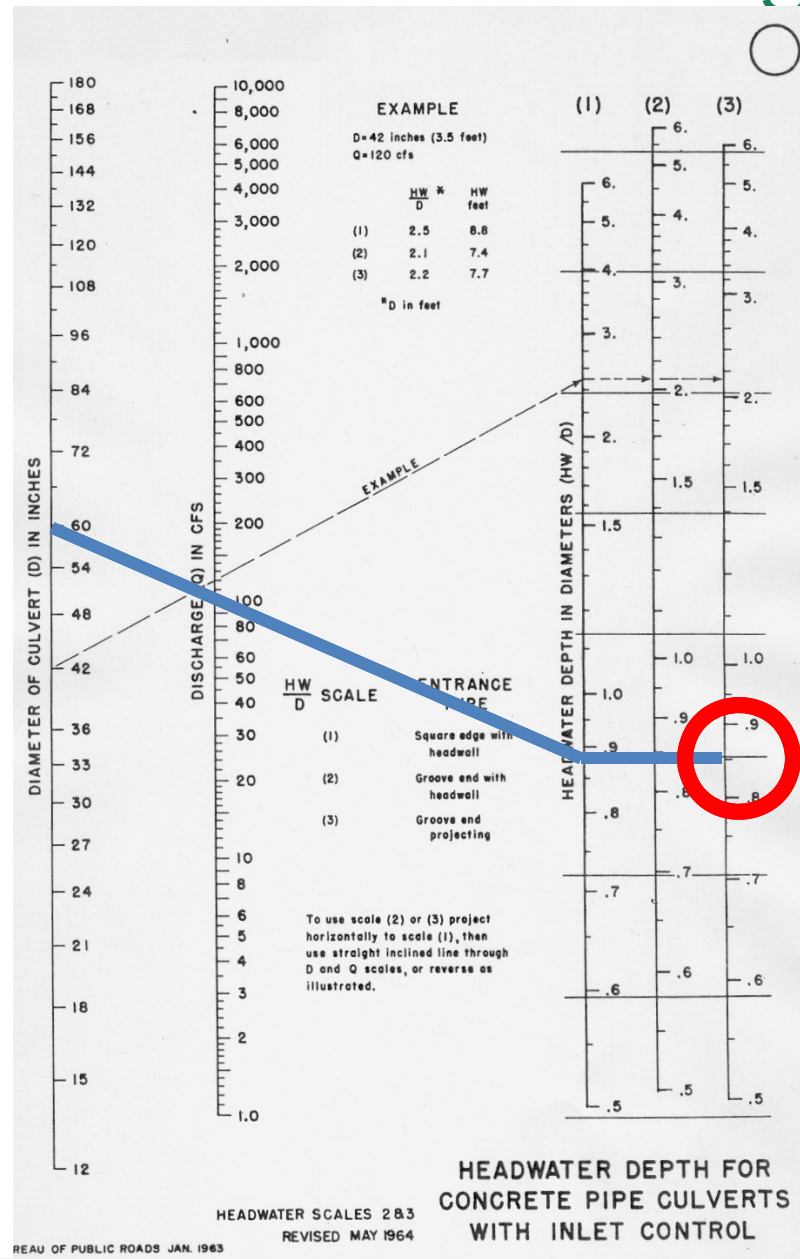
If we have an HW/D of 0.9 with a (3) entrance type and a flow rate of 100 cfs, what size culvert do we need?



(1) Is also the turning line

A 60 inch diameter round concrete culvert is needed since you round up to the next nominal size.

# Inlet Control Nomographs

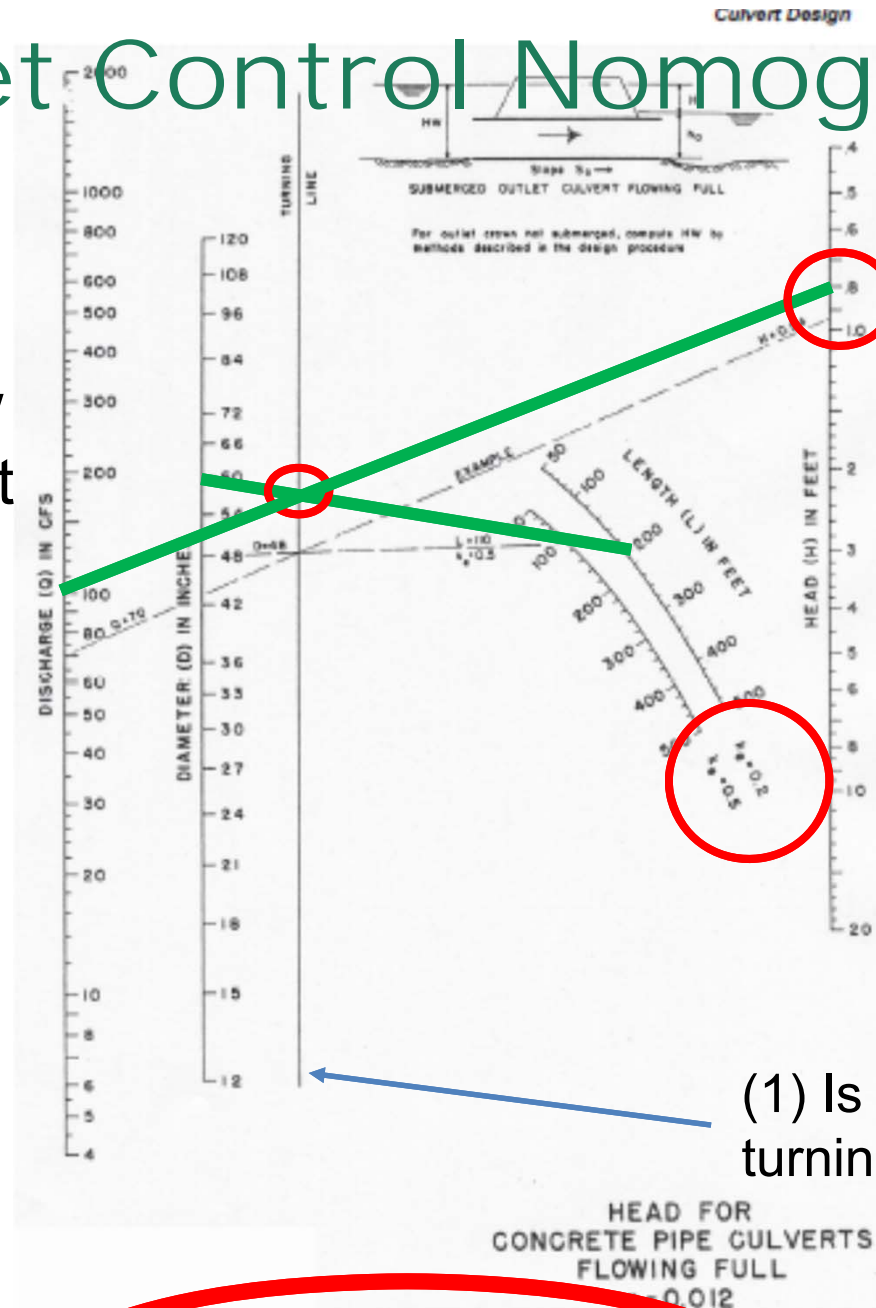


Using a 60 inch diameter culvert, the  $HW/d$  is now 0.85.



# Outlet Control Nomographs

Given a 200 foot long 60 inch diameter pipe with a flow of 100 cfs, what is the headloss  $H$  in feet? Assume a  $K_e$  of 0.2.



The outlet control nomograph shows a headloss  $H$  of 0.8 feet

# Group Designs

Exercises:

4) Culver Design Example 4 – we will do this now

Open up Culvert Design Example 4 packet and PowerPoint file!

# Roadside Drainage Ditch

A roadside drainage ditch primarily conveys roadway runoff. It may also convey offsite flows so the designer should be aware of where water is coming from that shows up in the roadside ditch.



# Roadside Drainage Ditch Sections

## 1. Rectangular Channel

$$D_c = \left[ \frac{C_1 Q}{b} \right]^{2/3}$$



Where  $C_1 =$  is 0.176 (English units) or 0.319 (metric units)

## 2. Triangular Channel

$$D_c = C_2 \left[ \frac{Q}{Z_1 + Z_2} \right]^{2/5}$$

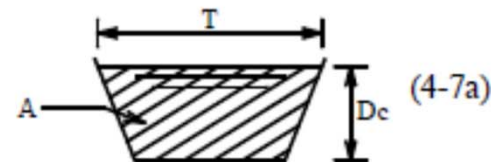


Where  $C_2 =$  is 0.757 (English units) or 0.96 (metric units)

## 3. Trapezoidal Channel

A trial and error or successive approximations approach is required with equation 4-7a when  $D_c$  is unknown:

$$Q = \left[ \frac{g A^3}{T} \right]^{1/2}$$



Where  $g =$  is the gravitational constant, 32.2 ft/s<sup>2</sup> (English units) or 9.81 m/s<sup>2</sup> (metric units)

$A =$  can be found using equation 4-5 in Figure 4-2.2.1

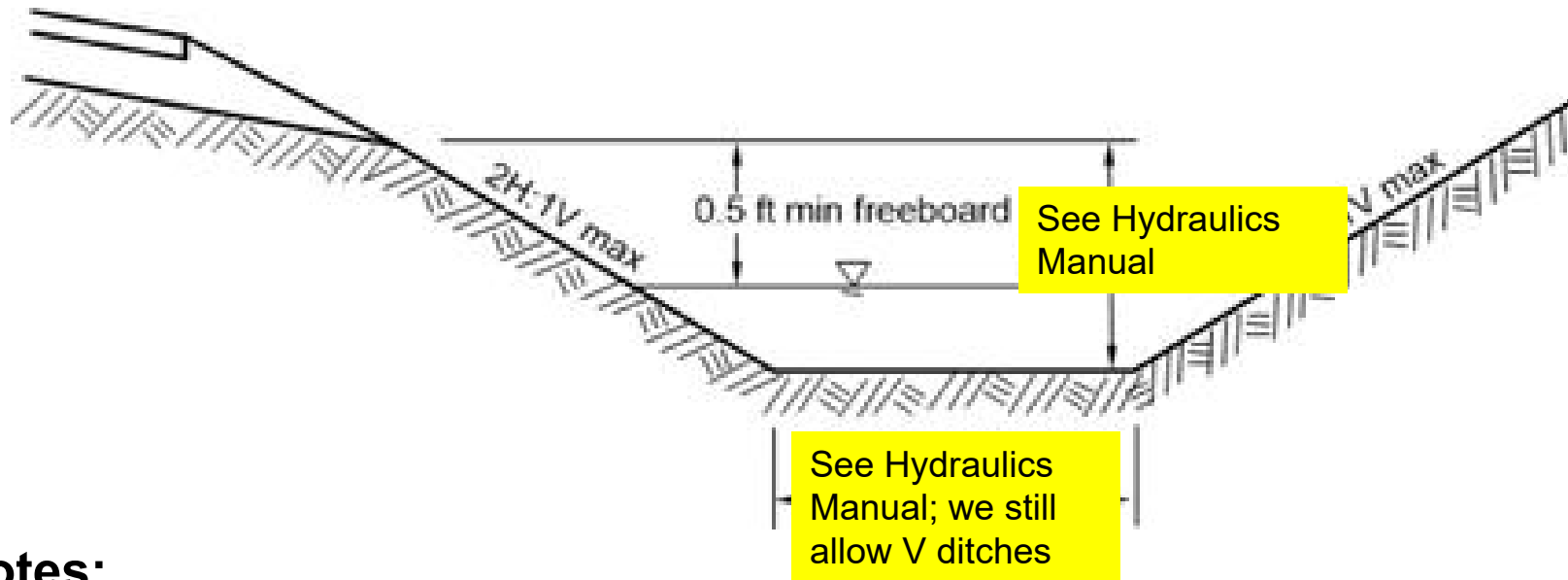
# Drainage Ditch Cheat Sheet

- Minimum ditch depth = water depth to convey the 10-year design event with a 0.5 foot minimum freeboard between the bottom of roadway subgrade to the 10-year design water surface elevation
- Maximum flow velocity of 5 feet per second and longitudinal ditch slope for grass lined ditches
- Trapezoidal section is preferred by “V” ditch is OK too
- Maximum ditch side slopes of 2:1
- Ditches are not biofiltration swales
- Make sure the 10 year water surface elevation is not equal to the critical depth
  - If the depth of flow is less than the critical depth, a hydraulic jump may occur

# Roadside Drainage Ditch Sections

## WSDOT Design Manual 2017

### Exhibit 1239-4 Drainage Ditch Details



#### Notes:

- Freeboard is the vertical distance from the bottom of base course to the 10-year storm water surface (see the Hydraulics Manual for more information.)
- Coordinate ditch design with region Hydraulics
- See Design Manual Errata sheet for ditch depth and width changes, may not be in the Design Manual until next year**



# Drainage Ditch Design Method

1. Calculate the ditch design flows
2. Select the type of ditch section (“V” or trapezoid)
3. Determine the depth of flow in the ditch using Manning's equation
4. Determine the critical depth and make sure the 10-year flow depth is not equal to the critical depth
5. Determine the roadway subgrade elevation to ensure minimum freeboard of 0.5 feet.
6. Determine ditch velocity for to determine if grass is ok or if another channel lining is needed